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A NOVEL DF-GSC-BASED ALGORITHM FOR ACTIVE CANCELLATION OF HOSTILE PROBING SOURCES

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ABSTRACT: *Adaptive arrays are of immense interest due to their ability to automatically steer nulls towards undesired interference sources, thereby reducing the output noise and enhancing the detection of desired signal. In active phased arrays, each antenna element is weighted for beamforming. These weights are estimated iteratively using different algorithms. Generalized sidelobe cancellers (GSC) are amongst the conventional adaptive beamformers that nullify the hostile probing signals (e.g. of radar) while simultaneously maintaining high output signal-to-interference-noise ratio (SINR) towards the desired one. However, GSC is quite sensitive to the direction-of-arrival mismatch. Further, the input signal is present in the stochastic gradient, which makes the gradient large, thereby requiring a very small step size. This further reduces the speed of convergence. In order to avoid such problems recently a modified scheme has been proposed in which the decision feedback filter is included in the conventional GSC scheme. This improves the robustness against various mismatch errors. Such designs are identified as decision feedback generalized sidelobe cancellers (DF-GSC). In this paper, an efficient receiver signal model is employed to investigate the capabilities of DF-GSC for two distinct narrowband radar sources probing the receiving antenna. Using the modified expression for eigenvalues of array correlation matrix and the optimum weight vectors, the performance parameters, viz. output SINR and mean square error are determined. First-order derivative constraints are included along with the point constraints in the LMS algorithm to improve the performance of sidelobe canceller schemes. The role of power level of the hostile sources in the generation of the adapted pattern is also investigated. It is demonstrated that the DF-GSC scheme can be considered as an efficient method for active phased arrays for nullifying the hostile probes while maintaining sufficient gain towards the desired signal. The interference suppression capabilities of DF-GSC scheme of phased arrays can be exploited for active RCS reduction.*

1. INTRODUCTION

Adaptive arrays are of immense interest due to their ability to automatically steer nulls onto undesired sources of interference, thereby reducing the output noise and enhancing the detection of desired signal. These have their roots in different fields including retrodirective antennas, self-phasing arrays, and sidelobe cancellers^[4]. In active phased arrays, each antenna element is weighted for beamforming. These weights are estimated iteratively using different algorithms. *Least mean square* (LMS) algorithms are iterative algorithms that are most popular because of their simplicity in implementation and superior performance.

Generalized sidelobe cancellers (GSC) are amongst the conventional adaptive beamformers that nullify the hostile probes (e.g. radar) while simultaneously maintaining high output *signal-to-interference-noise ratio* (SINR) towards the desired one. However, GSC is quite sensitive to the *direction of arrival* (DOA) mismatch. Further, the input signal is present in the stochastic gradient, which makes the gradient large, thereby requiring a very small step size. This further reduces the speed of convergence^[2]. In order to avoid such problems, Lee and Wu^[2] proposed the modified scheme in which the decision feedback filter is included in the conventional GSC scheme. This improves the robustness against various mismatch errors. Such designs are identified as *decision feedback generalized sidelobe cancellers* (DF-GSC).

In this paper, an efficient receiver signal model proposed by Godara^[1] is employed to investigate the capabilities of DF-GSC for two distinct narrowband radar sources probing the receiving antenna. Using the modified expression for eigenvalues of *array correlation matrix* (ACM) and the optimum weight vectors, the performance parameters, viz. output SINR and *mean square error* (MSE) are determined

(Sharma *et al.* [3]). First-order derivative constraints are included along with the point constraints in the LMS algorithm to improve the performance of sidelobe canceller schemes. The role of power level of the hostile sources in the generation of the adapted pattern is also investigated.

2. CONVENTIONAL APPROACH

The GSC is essentially a *linearly constrained minimum variance* (LCMV) implementation. In case of a mismatch, antenna array tends to misinterpret the desired signal with interference and thus tries to suppress it [3]. At the k^{th} snapshot, the received signal is expressed as

$$x(k) = S(\theta_0)s_0(k) + \sum_{m=1}^3 S(\theta_m)s_m(k) + n(k) = s(k) + i(k) + n(k) \quad (1)$$

where, $s(k)$ is the desired signal, $s_0(k)$ is the transmitted signal, $i(k)$ is the interfering signal, $S(\theta)$ is the steering vector and $n(k)$ is the noise. For optimization, the *mean square error* (MSE), J is given by

$$J = w^H R_x w \text{ subject to } C^H w = f \quad (2)$$

Here, R_x is the input correlation matrix, C is $N \times P$ constraint matrix and f is $P \times 1$ response vector, P being the number of constraints and w is the weight vector.

The output of GSC, $y(k)$ can be expressed as

$$y(k) = (w_q - Bw_a)^H x(k) \quad (3)$$

where, $w_q = C(C^H C)^{-1} f$ is a vector of dimension $N \times 1$, B is the blocking matrix of dimension $N \times (N-P)$, and w_a is $(N-P) \times 1$ weight vector.

Equation (2) can be re-written as

$$\min J = \min (w_q - Bw_a)^H R_x (w_q - Bw_a) \quad (4)$$

The weight, $w_{a,opt}$ is calculated as

$$w_a(k+1) = w_a(k) + \mu_a v(k) e^*(k) \quad (5)$$

where, μ_a is the step size controlling the convergence and the $v(k)$ is the output of blocking matrix. Since the GSC implementation reuses the array output signal as the error signal $e(k)$, we have, $e(k) = y(k)$.

If the optimum weight is $w_{opt} = w_q - B w_{a,opt}$, then the *minimum mean-squared error* (MMSE), denoted as J_{min} , is given by

$$J_{min} = w_{opt}^H R_x w_{opt} = w_q^H R_x w_{opt} \quad (6)$$

In case of GSC, the minimum output power is

$$P_{o,min} = J_{min} \quad (7)$$

The optimum SINR is

$$SINR_{opt} = \frac{P_s}{P_{o,min} - P_s} \quad (8)$$

where, P_s is the output signal power.

3. DECISION FEEDBACK FILTER

In DF-GSC, blind equalizer equates the channel and the DOA mismatch [2]. The role of feedback filter is to cancel any desired signal component in the LMS error signal. Since they are trained by different error signals, two different weights w_m and w_b are used.

The error signal used for training the blind equalizer is given by

$$e_m(k) = \hat{b}_0(k) - w_m^* y(k) \quad (9)$$

$\hat{b}_0(k)$ being the detected symbol and w_m is the equalizer tap weight.

Here, w_{opt} consists of two parts, i.e. $w_{opt} = [w_a \ w_b]^T$ where, w_b is the feedback weight with a dimension of 1×1 . The weights w_a and w_b are calculated recursively using LMS algorithm.

4. NUMERICAL RESULTS

A *uniform linear array* (ULA) of $N = 16$ antenna elements, spaced half-a-wavelength apart is considered. It is assumed that there is one desired source at 0° and two uncorrelated narrowband hostile radar sources probing at say, 20° , and 45° respectively. The power ratios of the hostile sources are taken to be distinct (10 and 100). Noise is modeled as white gaussian noise with variance 0.35. The modulation of the received signal is taken to be similar to that employed by Lee and Wu [2] in order to facilitate the comparison.

Figure 1 shows the learning curves of GSC and DF-GSC schemes. It is apparent that DF-GSC has far better performance. The corresponding beam pattern for GSC and DF-GSC (Fig. 2) demonstrate the superior capability of DF-GSC in placing nulls at the hostile source location. The quiescent pattern is shown as dotted curve. It is readily apparent that DF-GSC has far better performance than the conventional scheme. Further, the SINR level obtained are higher than those reported by Lee and Wu [2].

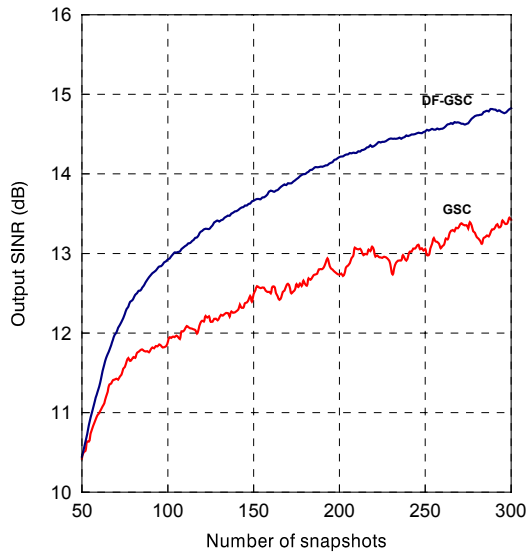


Fig. 1 Learning curves of GSC and DF-GSC schemes

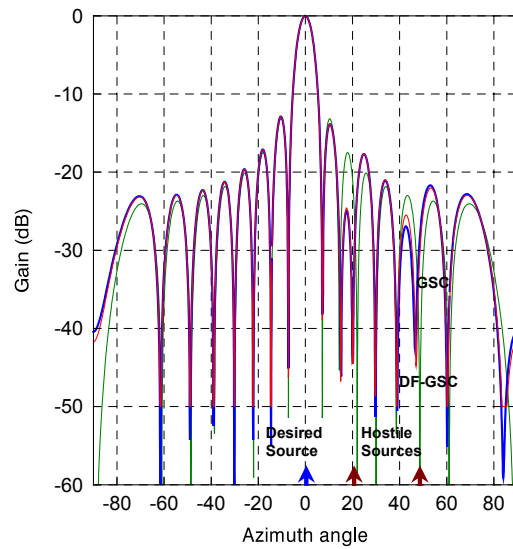


Fig. 2 Adapted beam pattern of GSC (---) and DF-GSC (___)

In order to compare the convergence rate for both the schemes, the learning curves for GSC and DF-GSC with identical SINR target are shown in Fig. 3. It is clear from the graph that DF-GSC converges much faster than GSC to reach the optimal output SINR. Again the SINR achieved by both GSC and DF-GSC are higher than those studied by Lee and Wu [2].

In order to analyze the performance of sidelobe cancellers in an environment of hostile sources with different power levels, the learning curves of DF-GSC are presented in Fig. 4. It establishes that array has a better performance when difference between the power level of hostile sources is more.

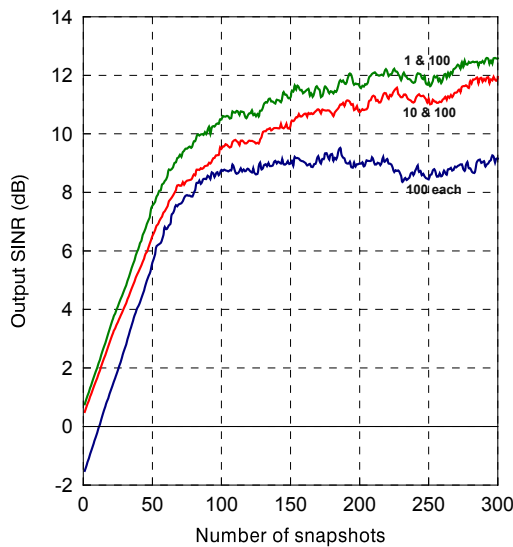


Fig. 3 Learning curves of GSC and DF-GSC for a given SINR target

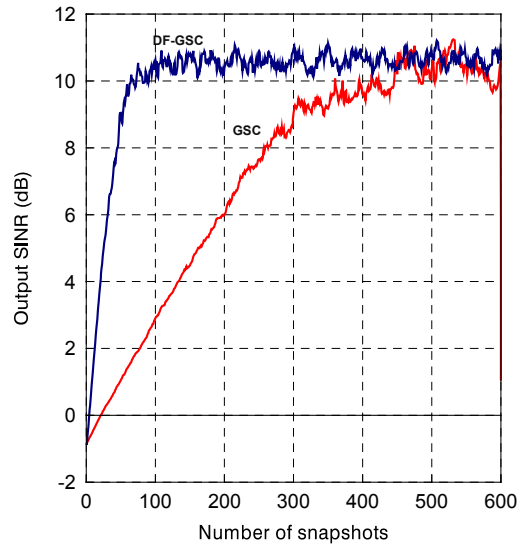


Fig. 4 Effect of varying power level of the hostile sources in DF-GSC scheme

5. CONCLUSIONS

The performance of *decision-feedback generalized sidelobe canceller* (DF-GSC) is analyzed in this paper so as to exploit the interference suppression capabilities of arrays for active RCS reduction. Addition of blind equalizer with decision feedback in conventional GSC provides better robustness, faster convergence and high output SINR. It is apparent from the results obtained that the DF-GSC achieves higher SINR value for the same convergence rate than the conventional GSC. Deeper nulls are placed indicating the superior suppression capabilities of the scheme.

Furthermore, it is shown that higher the power level of the radar source, more accurately the nulls can be placed by an antenna array. This is because if the power level of the source is high, antenna can efficiently differentiate between the interference and inherent noise. Thus, it is inferred that on mounting the active phased arrays in suitable configurations on aircraft and missiles, it will be possible to achieve an efficient method of suppressing the probing effect of hostile radars while maintaining sufficient gain towards the desired signal.

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